VOLUME VIII: CHAPTER 12

METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM MUNICIPAL WASTEWATER

October 1999

Prepared by:
ICF Consulting

Prepared for:
Greenhouse Gas Committee
Emission Inventory Improvement Program

DISCLAIMER

This document was prepared for the Emission Inventory Improvement Program and the U.S. Environmental Protection Agency by ICF Incorporated, Washington, D.C. This report is intended to be a working draft document and has not been reviewed or approved for publication. The opinions, findings, and conclusions are those of the authors and not necessarily those of the Emission Inventory Improvement Program or the U.S. Environmental Protection Agency. Mention of company or product names is not to be considered an endorsement by the Emission Inventory Improvement Program or the U.S. Environmental Protection Agency.

ACKNOWLEDGMENTS

The text for this document was originally written by staff of the ICF Consulting Group in Washington, DC, drawing on a variety of sources. It has since been updated by Anne Choate, Randy Freed, William Driscoll, and other staff of ICF, for the Greenhouse Gas Committee of the Emission Inventory Improvement Program and for Ethan McMahon and Wiley Barbour of the Office of Policy of the U.S. Environmental Protection Agency. Bill Irving, of U.S. EPA's Office of Air and Radiation, also contributed to this report. Members of the Greenhouse Gas Committee contributing to the preparation of this document were:

Mike Aucott, Program Analyst, New Jersey Department of Environmental Protection
Peter Ciborowski, Environmental Protection Specialist, Minnesota Pollution Control Agency
Guido Franco, Program Analyst, California Energy Commission
William Herz, Assistant Research Engineer, University of Alabama
Joe Loyer, Program Analyst, California Energy Commission

CONTENTS

TABLES

Table **Page**

1

INTRODUCTION

The purposes of the preferred methods guidelines are to describe emissions estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating greenhouse gas emissions from municipal wastewater.

Section 2 of this chapter contains a general description of the municipal wastewater source category. Section 3 provides an overview of the preferred and alternate methods for estimating greenhouse gas emissions from this source. Section 4 presents the preferred estimation method; Section 5 presents an alternative estimation technique. Quality assurance and quality control procedures are described in Section 6. References used in developing this chapter are identified in Section 7.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Disposal and treatment of industrial and municipal wastewater often results in methane emissions. Wastewater may be treated using aerobic and/or anaerobic technologies, or if untreated, may degrade under either aerobic or anaerobic conditions. Methane is produced when organic material in treated and untreated wastewater degrades anaerobically, i.e., in the absence of oxygen.

In highly organic wastewater streams, e.g., from food processing plants or pulp and paper plants, the available oxygen in the water is rapidly depleted as the organic matter decomposes. The organic content (sometimes known as "loading") of these wastewater streams, is expressed in terms of biochemical oxygen demand, or "BOD." BOD represents the amount of oxygen taken up by the organic matter in the wastewater during decomposition. Under the same conditions, wastewater with a higher BOD will produce more methane than wastewater with a lower BOD.

Nitrous oxide (N_2O) is emitted from both domestic and industrial wastewater containing nitrogen-rich organic matter. N_2O is produced through the natural processes of nitrification and denitrification. Nitrification occurs aerobically and converts ammonia into nitrate, whereas denitrification occurs anaerobically, and converts nitrate to N_2O. Human sewage is believed to constitute a significant portion of the material responsible for N_2O emissions from wastewater (Spector, 1997). There is not sufficient information available at this time to accurately estimate N_2O emissions from industrial wastewater and other components of domestic wastewater.

Sludge is produced as a byproduct of wastewater treatment, and must often be treated separately before disposal. Like wastewater, sludge can be treated using aerobic and/or anaerobic technologies, and will produce methane under anaerobic conditions.

2.2 FACTORS INFLUENCING EMISSIONS

Methane production in wastewater systems is influenced primarily by BOD loading and also by temperature, retention time, and lagoon maintenance and depth. Nitrous oxide generation is affected by temperature, pH, BOD loading, and nitrogen concentration.

Facultative anaerobic lagoons are often used for storage and treatment. EPA estimated in 1987 that there were approximately 5,500 municipal waste stabilization lagoons in the U.S. The CH_4 potential from these lagoons is not well understood and little field data are available. Industrial and commercial wastewater processes also use lagoons for treatment and storage. Facultative lagoons, the most common type, treat wastewater by both anaerobic fermentation and aerobic processes. At the bottom of the lagoon, where an anaerobic environment exists, organic matter is digested to CH_4 and CO_2. As these gases bubble to the surface, much of the CO_2 is absorbed and used by algae, along with nutrients liberated during digestion. Aerobic conditions, supported by algae growth, are maintained near the surface. Between 20 and 30 percent of the BOD loading to a facultative pond is anaerobically metabolized. As BOD loading increases and natural surface aeration diminishes, facultative lagoons proceed to a more anaerobic state. This results in higher CH_4 production, providing that the temperature is higher than 59° F; below this temperature the lagoons serve principally as a sedimentation tank.

3

OVERVIEW OF AVAILABLE METHODS

The data required to estimate methane emissions from municipal wastewater are not easily obtained; data for industrial wastewater are even more difficult to obtain. Because of the difficulty in obtaining data for industrial wastewater, estimating emissions from this source is optional, and the methodology is presented as an alternate methodology. The alternate methodology section also presents a more precise methodology for calculating methane emissions from municipal wastewater and sludge.

To estimate methane emissions from municipal wastewater, the following steps are required: (1) obtain data on state population; (2) estimate total biochemical oxygen demand (BOD_5)[1] produced; (3) estimate gross annual methane emissions from wastewater; (4) estimate net annual methane emissions from wastewater; (5) estimate gross annual methane emissions from sludge, and (6) estimate net annual methane emissions from sludge.

Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this volume represent the work of the EIIP Greenhouse Gas Committee in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).

There have been several recent developments in inventory methodologies, including:

- Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources and present the U.S. methodologies in a more transparent manner than in previous inventories;
- Initiation of several new programs with industry, which provide new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
- The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.

Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories. EPA intends to provide periodic updates to the EIIP chapters to reflect important methodological developments. To determine whether an updated version of this chapter is available, please check the EIIP site at http://www.epa.gov/ttn/chief/eiip/techrep.htm#green.

[1] A standardized measurement of BOD is the "5-day test" denoted as BOD_5.

To estimate N_2O emissions from wastewater, the following steps are required: (1) obtain data on the state's population, (2) estimate annual per capita consumption of nitrogen in protein, (3) estimate the state's annual consumption of nitrogen in protein, and (4) estimate the state's annual N_2O emissions from wastewater.

The methods described here are taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997). These methods are used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 1998), except that the U.S. inventory does not distinguish between methane emissions from wastewater and those from sludge, and does not estimate methane emissions from industrial wastewater.

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

4.1 METHANE EMISSIONS FROM MUNICIPAL WASTEWATER AND SLUDGE

The following two equations present the approach to calculating methane emissions from wastewater and sludge, respectively.

Methane Emissions from Wastewater

$$\frac{\text{lbs CH}_4}{\text{yr}} = (\text{population})\left(\frac{\text{lbs BOD}_5}{\text{capita / day}}\right)\begin{pmatrix}1-\text{Fraction of}\\ \text{BOD Removed}\\ \text{as Sludge}\end{pmatrix}\left(\frac{365\text{ days}}{\text{yr}}\right)\left(\frac{0.22\text{ lb CH}_4}{\text{lb BOD}_5}\right)\begin{pmatrix}\text{Fraction}\\ \text{Anaerobically}\\ \text{Treated}\end{pmatrix}-\begin{pmatrix}\text{Methane}\\ \text{Recovered}\end{pmatrix}$$

Methane Emissions From Sludge

$$\frac{\text{lbs CH}_4}{\text{yr}} = (\text{population})\left(\frac{\text{lbs BOD}_5}{\text{capita / day}}\right)\begin{pmatrix}\text{Fraction of}\\ \text{BOD Removed}\\ \text{as Sludge}\end{pmatrix}\left(\frac{365\text{ days}}{\text{yr}}\right)\left(\frac{0.22\text{ lb CH}_4}{\text{lb BOD}_5}\right)\begin{pmatrix}\text{Fraction}\\ \text{Anaerobically}\\ \text{Treated}\end{pmatrix}-\begin{pmatrix}\text{Methane}\\ \text{Recovered}\end{pmatrix}$$

Step (1) Obtain Required Data

- *Required Data.* The information needed to calculate methane emissions from municipal wastewater are (1) lbs BOD_5 per capita per day; (2) state population; (3) the fraction of BOD_5 removed as sludge; (4) the fraction of total wastewater that is treated anaerobically; (5) the fraction of total sludge that is treated anaerobically; (6) the amount of methane from wastewater that is recovered; and (7) the amount of methane from sludge that is recovered.

- *Data Sources.* Population data may be obtained from state agencies responsible for handling demographic or census information. Information on BOD_5 and wastewater characteristics may be obtained from *National Small Flows Clearinghouse* (West Virginia University), *Water Supply and Pollution Control* (Viessman and Hammer, 1985), *Emissions and Mitigation at Landfills and Other Waste Management Facilities* (Thorneloe, 1992), and state and local public works agencies.

  Published data on the fraction of wastewater and sludge treated anaerobically are scarce; however, EPA's Office of Water maintains a database of information on wastewater treatment facilities including information on population served and treatment methods.

This information can be found on the Internet at http://www.epa.gov/owm/foi.htm (US EPA 1999). If state-specific data are not available, this section contains default values for the fraction of wastewater and sludge treated anaerobically.

- *Units for Reporting Data.* Population data should be reported in units of the number of persons. BOD_5 data should be reported in pounds per capita per day.

Step (2) Estimate Biochemical Oxygen Demand (Table 12.4-1, Columns A, B, and C)

- Enter the total state population in Table 12.4-1, column A. Enter wastewater BOD_5 generation rate in Table 12.4-1, column B. (The IPCC default value of 0.11 lbs/capita/day may be used if state-specific data are not available).

- Multiply the population by wastewater BOD_5 generation rate to obtain daily BOD generated. Enter the result in pounds BOD_5, in column C of Table 12.4-1.

$$\text{Population} \times BOD_5 \text{ Generation Rate (lbs/capita/day)} = BOD_5 \text{ Generated (lbs/day)}$$

Example A state that has a current population of 2 million people would calculate its BOD_5 generated as follows:

$$2{,}000{,}000 \text{ persons} \times 0.11 \text{ lbs/capita/day} = 220{,}000 \text{ lbs/day}$$

Step (3) Estimate Gross Annual Methane Emissions from Wastewater (Table 12.4-1, Columns C, D, E, F, G, and H)

- Enter fraction of BOD removed as sludge in Table12.4-1, column D. (A default value of 0.90 may be used if state-specific data are not available.[2])
- Enter fraction of wastewater BOD treated anaerobically in Table 12.4-1, column E. (A default value of 15 percent may be used if state-specific factors are unavailable.)
- Multiply annual BOD generated by (1) 1 - the fraction of BOD removed as sludge; (2) the fraction of wastewater BOD treated anaerobically and (3) 365 days/yr, to obtain the quantity of BOD treated anaerobically per year. Enter this result, in pounds BOD_5 per year, in column F.

$$BOD_5 \text{ Generated (lbs } BOD_5\text{/day)} \times (1 - \text{Fraction of BOD removed as sludge}) \times \text{Fraction of Wastewater } BOD_5 \text{ Treated Anaerobically} \times 365 \text{ days/yr} = BOD_5 \text{ Treated Anaerobically (lbs } BOD_5\text{/yr)}$$

[2] This value was suggested by Robert Reimers, a professor of Environmental Health Science at Tulane University.

Example Wastewater BOD_5 treated anaerobically per year in the state is estimated as follows:

220,000 (lbs BOD_5/day) × (1-0.90) × 0.15 × 365 (days/yr) = 1,200,000 (lbs BOD_5/yr)

- Enter the methane emissions factor, in lbs CH_4/lb BOD_5, in column G. The recommended emissions factor is 0.25 lbs CH_4/lbs BOD_5.

- Multiply the quantity of BOD treated anaerobically times the methane emissions factor to obtain the total methane emissions (in pounds). Enter the result in column H.

  BOD_5 Treated Anaerobically × Methane Emissions Factor (lbs CH_4/lb BOD_5)
  = Methane Emissions (lbs CH_4)

Example Gross methane emissions from wastewater treatment in the state are calculated as follows:

1,200,000 (lbs BOD_5/yr) × 0.25 lbs CH_4/lbs BOD_5 = **300,000 lbs CH_4/yr**

Step (4) Estimate Net Annual Methane Emissions from Wastewater (Table 12.4-1, Columns I and J)

- Estimate the amount of methane recovered (if any) from municipal wastewater treatment. Enter the result, in pounds CH_4, in column I.

- Perform the calculation shown in column J to obtain net methane emissions and convert the emissions to units of metric tons of carbon equivalent. In this calculation, the initial subtraction yields the value for net methane emissions. The remainder of the calculation converts net methane emissions from (1) pounds to metric tons, and (2) metric tons to metric tons of carbon equivalent (by multiplying by the mass ratio of carbon to carbon dioxide, and by the global warming potential for methane, i.e., 21).

  [Methane Emissions (lbs CH_4) - Methane Recovered (lbs CH_4)] ÷ 2,205 lbs/metric ton
  × (12/44) × 21 = Net Methane Emissions (MTCE CH_4)

Example A state that recovers 15 percent of the methane generated from wastewater treatment would calculate its net emissions, in MTCE CH_4 as follows:

[300,000 lbs/CH_4 - (0.15 × 300,000 lbs CH_4)] ÷ 2,205 × (12/44) × 21 = 660 MTCE CH_4

Step (5) Estimate Gross Annual Methane Emissions from Sludge (Table 12.4-2, Columns A, B, C, D, E and F)

- Enter the BOD generation from Table 12.4-1, column C into Table 12.4-2, column A.
- Enter Fraction of BOD removed as sludge in Table 12.4-2, column B. (A default value of 0.90 may be used if state-specific data are not available.[3])
- Enter Fraction of Sludge BOD treated anaerobically in Table 12.4-2, column C. (A default value of 15 percent may be used if state-specific factors are unavailable.)
- Multiply BOD generated by (1) the fraction of BOD removed as sludge; (2) the fraction of sludge BOD treated anaerobically and (3) 365 days/yr, to obtain the quantity of sludge BOD treated anaerobically per year. Enter this result, in pounds BOD_5, in column D.

  BOD_5 Generated (lbs BOD_5/day) $\times$ Fraction of BOD_5 removed as sludge $\times$ Fraction of Sludge BOD_5 Treated Anaerobically $\times$ 365 days/yr = Sludge BOD_5 Treated Anaerobically (lbs BOD_5/yr)

Example	Sludge BOD_5 treated anaerobically per year in the state is estimated as follows:
	220,000 (lbs BOD_5/day) $\times$ 0.90 $\times$ 0.15 $\times$ 365 (days/yr) = 11,000,000 (lbs BOD_5/yr)

- Enter the sludge methane emissions factor, in pounds CH_4/lb BOD_5, in column E. The recommended emissions factor is 0.25 lbs CH_4/lb BOD_5.

- Multiply the quantity of Sludge BOD treated anaerobically times the methane emissions factor to obtain the total methane emissions. Enter the result in pounds CH_4 in column F.

  Sludge BOD_5 Treated Anaerobically $\times$ Sludge Methane Emissions Factor (lbs CH_4/lb BOD_5) = Sludge Methane Emissions (lbs. CH_4)

Example	Gross methane emissions from sludge treatment in the state are calculated as follows:
	11,000,000 (lbs BOD_5/yr) $\times$ 0.25 lbs CH_4/lbs BOD_5 = **280,000 lbs CH_4/yr**

[3] This value was suggested by Robert Reimers, a professor of Environmental Health Science at Tulane University.

Step (6) Estimate Net Annual Methane Emissions from Sludge (Table 12.4-2, Columns G and H)

- Estimate the amount of methane recovered (if any) from municipal sludge treatment. Enter the result, in pounds CH_4, in column G.

- Perform the calculation shown in column H to obtain net methane emissions and convert the emissions to units of metric tons of carbon equivalent. In this calculation, the initial subtraction yields the value for net methane emissions. The remainder of the calculation converts net methane emissions from (1) pounds to metric tons, and (2) metric tons to metric tons of carbon equivalent (by multiplying by the mass ratio of carbon to carbon dioxide, and by the global warming potential for methane, i.e., 21).

  Total Methane Emissions (lbs CH_4) - Methane Recovered (lbs CH_4)]
  $\div$ 2,205 lbs/metric ton $\times$ (12/44) $\times$ 21 = Net Methane Emissions (MTCE CH_4)

Example	A state that recovers 15 percent of the methane generated from sludge treatment would calculate its net emissions, in MTCE CH_4 as follows: [2,800,000 lbs CH_4 - (0.15 $\times$,2,800,000 lbs CH_4)] $\div$ 2,205 $\times$ (12/44) $\times$ 21 = 6,200 MTCE CH_4

4.2 N_2O EMISSIONS FROM WASTEWATER AND SLUDGE

The following equation presents the N_2O calculation from sewage in wastewater:

$$N_2O(s) = (Protein) \times (Frac_{NPR}) \times (Population) \times (EF)$$

Where:
$N_2O(s)$ = N_2O emissions from human sewage
Protein = Annual per capita protein consumption
$Frac_{NPR}$ = fraction of nitrogen in protein
Population = state population
EF = emission factor

Step (1) Obtain Required Data

- *Required Data.* The data needed to calculate nitrous oxide emissions from municipal wastewater are (1) annual per capita protein consumption, (2) the fraction of nitrogen in protein, (3) the state population, and (4) the emission factor.

- *Data Sources*. Where state data are available, they should be used. Otherwise, data on annual per capita protein consumption for the US are available from the United Nations

Food and Agriculture Organization (FAO 1997). In 1995 (the most recent year for which data were available as of this writing), US annual per-capita protein intake was 39.79 kilograms. The fraction of nitrogen in protein has been calculated at 16 percent (IPCC 1997). Population data may be obtained from state agencies responsible for handling demographic or census information. An emission factor has not been estimated for the US; thus, the default IPCC value of 0.01 kg N_2O-N/kg sewage-N) should be used (IPCC 1997).

- *Units for Reporting Data*. Annual per capita protein consumption should be reported in kilograms. The equation will then yield an estimate of the state's annual N_2O emissions in kilograms of N_2O-N; this value should then be converted to metric tons of carbon equivalent of N_2O.

Step (2) Estimate Annual Per Capita Consumption of Nitrogen in Protein

- Multiply the annual per capita consumption of protein by the percentage of nitrogen in protein, to obtain the annual per capita consumption of nitrogen in protein.

Annual per capita consumption of protein (kg) × Percentage of nitrogen in protein (%) = Annual per capita consumption of nitrogen in protein (kg)

Example	In the US in 1995, annual per capita consumption of protein was 39.79 kg. The percentage of nitrogen in protein is 16 percent. The calculation for the US for 1995 would be: 39.79 kg protein × 16% N in protein = 6.37 kg N per capita

Step (3) Estimate the State's Annual Consumption of Nitrogen in Protein

- Multiply the annual per capita consumption of nitrogen in protein by the state population to obtain the state's annual consumption of nitrogen in protein.

Annual per capita consumption of nitrogen in protein × State population = State's annual consumption of nitrogen in protein

Example	For a state with a population of 5 million, the calculation would be: 6.37 kg N × 5 million = 31.9 million kg N

Step (4) Estimate the State's Annual N_2O Emissions from Wastewater

- Multiply the state's annual consumption of nitrogen in protein by the emission factor (0.01 kg N_2O-N/kg N in protein) to obtain the state's annual emissions of N_2O from wastewater.

State's annual consumption of nitrogen in protein × Emission factor =
State's annual emissions of N_2O from wastewater

Example	For a state with a population of 5 million, the calculation would be: 31.9 million kg N × 0.01 kg N_2O-N/kg N in protein = 0.32 million kg N_2O-N

Step (5) Convert the Units to Metric Tons of Carbon Equivalent of N_2O

- To convert the units, perform the following calculations:
  - Divide kg of N_2O-N by 1000 to obtain metric tons of N_2O-N.
  - Multiply metric tons of N_2O-N by the mass ratio of N_2O to N (44/28) to obtain metric tons of N_2O.
  - Multiply metric tons of N_2O by the mass ratio of carbon to carbon dioxide (12/44) and by the global warming potential for N_2O (310) to obtain metric tons of carbon equivalent of N_2O.

N_2O from wastewater (kg N_2O-N) ÷ (1000 kg/metric ton) × (44/28) × (12/44) × 310 =
N_2O from wastewater (metric tons N_2O)

Example	For a state with a population of 5 million, the calculation would be: 0.32 million kg N_2O-N ÷ 1000 × 44/28 × (12/44) × 310 = 42,300 metric tons of carbon equivalent N_2O

Table 12.4-1. Worksheet to Estimate Methane Emissions from Municipal Wastewater Treatment

A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
		(A × B)			*[C × (1-D) × E × 365]*		*(F × G)*		*[(H-I)) 2,205 × (12/44) × 21]*
Population (persons)	Wastewater BOD Generation Rate (lbs BOD_5/ capita/day)	BOD Generated (lbs BOD_5/day)	Fraction of BOD removed as sludge	Fraction of Wastewater BOD Treated Anaerobically	Quantity of BOD Treated Anaerobically (lbs BOD_5/yr)	Methane Emission Factor (lbs CH_4/lb BOD_5)	CH_4 Emissions (lbs CH_4)	Methane Recovered (lbs CH_4)	Net CH_4 Emissions (MTCE CH_4)

Table 12.4-2. Worksheet to Estimate Methane Emissions from Municipal Sludge Treatment

A ***From Table 12.4-1, Col. C***	***B***	***C***	***D*** ***[A × B × C × 365]***	***E***	***F*** ***(D × E)***	***G***	***H*** ***[(F - G) ÷ 2,205] × (12/44) × 21***
BOD Generated (lbs BOD_5/day)	Fraction of BOD removed as sludge	Fraction of Sludge BOD Treated Anaerobically	Quantity of BOD Treated Anaerobically (lbs BOD_5/yr)	Methane Emission Factor (lbs CH_4/lb BOD_5)	CH_4 Emissions (lbs CH_4)	Methane Recovered (lbs CH_4)	Net CH_4 Emissions (MTCE CH_4)

5

ALTERNATE METHODS FOR ESTIMATING EMISSIONS

This section presents an alternative method for estimating methane emissions from municipal wastewater, as well as two approaches—one simple, the other more complex—to estimating methane emissions from industrial wastewater.

Municipal Wastewater

A more precise estimate of methane emissions from wastewater treatment for a given state is possible, if the following additional data are available: (1) the different wastewater and sludge treatment methods used in the state; (2) the total portion of wastewater and sludge that is treated using each of these methods; and (3) the methane conversion factor (MCF) of each of these treatment methods. These data would be used in combination with standard values (from IPCC 1997) for the amount of BOD_5 per capita per day (0.11) and for the maximum methane producing capacity of wastewater (0.25 pounds CH_4 per pound BOD_5).

Where data are available, the following equation would be used to estimate methane emissions:

Methane Emissions from Municipal Wastewater – Complex Method

$$\frac{\text{lbs CH}_4}{\text{year}} = \sum_{i=1}^{n} (\text{Population}) \left(\frac{\text{lbs BOD}_5}{\text{capita/day}} \right) \left(\frac{365 \text{ days}}{\text{yr}} \right) \left(\frac{0.25 \text{ lbs CH}_4}{\text{lb BOD}_5} \right) \begin{pmatrix} \text{Fraction} \\ \text{Wastewater} \\ \text{Treated} \\ \text{Using} \\ \text{Method}_i \end{pmatrix} \begin{pmatrix} \text{MCF for} \\ \text{Method}_i \end{pmatrix} - \begin{pmatrix} \text{Methane} \\ \text{Recovered} \end{pmatrix}$$

Unfortunately, many states may not have data on the portion of wastewater and sludge treated using different methods. Additionally, as of the publication date of this report, MCFs had not yet been developed for all wastewater and sludge treatment systems. States which have (1) more detailed information on specific treatment methods, and (2) the corresponding MCFs, are encouraged to use this information to estimate methane emissions from wastewater treatment.

Industrial Wastewater

To estimate methane emissions from industrial wastewater and sludge treatment, the following data are required:

- Relevant industries within a state;
- Amount of wastewater flow by industry;

- Oxygen demand from organic or inorganic material in the wastewater (expressed as Chemical Oxygen Demand, or COD);
- COD removed as sludge;
- Amount of wastewater anaerobically treated;
- Methane recovered from wastewater treatment;
- Amount of sludge anaerobically treated;[4] and
- Methane recovered from sludge treatment.

After the relevant data have been obtained, methane emissions can be estimated in the same manner as described above in section 4 to estimate methane emissions from the treatment of municipal wastewater.

Step 1: Estimate wastewater flow by industry. If these data are not directly available, they may be estimated based on the production by industry, and water consumed per unit of product. Typical water consumption rates for some key industries are presented in Table 12.5-1.

Step 2: Estimate the COD of the wastewater for each industry. Default COD values are provided in Table 12.5-1.

Step 3: Estimate the amount of COD removed as sludge.

Step 4: Estimate the fraction of wastewater and sludge from each industry that is treated anaerobically. Unfortunately, default values are not available by industry.

Step 5: If anaerobic treatment with methane recovery is employed, subtract the amount of methane recovered from the estimate of total methane production.

Step 6: Sum the net methane emission estimates for each industry across all relevant industries in the state.

The following equation summarizes the emissions calculation for industrial wastewater treatment:

Methane Emissions from Industrial Wastewater – Simplified Approach

$$\frac{\text{lbs } CH_4}{\text{year}} = \sum_{i=1}^{n} \begin{pmatrix} \text{Wastewater} \\ \text{Flow For} \\ \text{Industry } i \end{pmatrix} \left(\frac{\text{lbs COD}}{\text{Cubic meter of wastewater}} \right) \left(\frac{0.25 \text{ lbs } CH_4}{\text{lb COD}} \right) \begin{pmatrix} \text{Fraction} \\ \text{Anaerobically} \\ \text{Treated} \end{pmatrix} - \begin{pmatrix} \text{Methane} \\ \text{Recovered} \end{pmatrix}$$

[4] Note that methane generation from industrial wastewater sludge disposed in landfills is accounted for in the methodology for landfill methane emissions (Chapter 5).

As with methane emissions from municipal wastewater treatment, the methane emissions from industrial wastewater and sludge treatment may be estimated more precisely if (1) specific methods used to treat wastewater flow from each industry are known and (2) the MCFs for each method have been estimated. If this information is available, the following equation may be used:

Methane Emissions from Industrial Wastewater – Complex Method

$$\frac{\text{lbs CH}_4}{\text{year}} = \sum_{m=1}^{n}\sum_{i=1}^{n}\begin{pmatrix}\text{Wastewater}\\ \text{Flow for}\\ \text{Industry } i\end{pmatrix}\left(\frac{\text{lbs COD}}{\text{Cubic meter of wastewater}}\right)\left(\frac{0.25\text{ lbs CH}_4}{\text{lb COD}}\right)\begin{pmatrix}\text{Fraction}\\ \text{Wastewater}\\ \text{Treated Using}\\ \text{Method } m\end{pmatrix}\begin{pmatrix}\text{MCF for}\\ \text{Method } m\end{pmatrix} - \begin{pmatrix}\text{Methane}\\ \text{Recovered}\end{pmatrix}$$

Table 12.5-1. Water Consumption and COD Value Per Unit of Production, for Selected Industries

Process	Wastewater Produced (m^3/ton of product)	COD Value (pounds COD/m^3 wastewater)
Beverage-Distilled & Industry Generic - ethanol	13 m^3/m^3 ethanol	88
Beverage-Malt & Beer (choose one set of values) Generic – 1st set of values Generic – 2nd set of values	5 m^3/m^3 beer 5-9 m^3/m^3 beer	37 4.4 – 15.4
Food-Oils	1.45	0.7
Pulp & Paper Generic (pulp) North America (virgin paper) North America (recycled paper)	53 88 40	4.4 – 33 3.5 6.6
Source: IPCC 1997		

6

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are essential elements in producing high quality emission estimates and should be included in all methods to estimate emissions. QA/QC of emissions estimates are accomplished through a set of procedures that ensure the quality and reliability of data collection and processing. These procedures include the use of appropriate emission estimation methods, reasonable assumptions, data reliability checks, and accuracy/logic checks of calculations. Volume VI of this series, *Quality Assurance Procedures*, describes methods and tools for performing these procedures.

There is uncertainty in estimating emissions from wastewater due to a lack of data characterizing (1) wastewater management practices, (2) the quantities of wastewater that are subject to anaerobic conditions, (3) the extent to which methane is emitted under anaerobic conditions, and (4) methane recovery or flaring practices.

The effluent of wastewater treatment plants and all other waste that is disposed of in surface water can also lead to methane and nitrous oxide emissions from inland and coastal waters. The same applies to untreated sewage or excess manure and fertilizer application. Runoff can lead to surface water pollution and related methane and nitrous oxide emissions. However, methods for estimating emissions from these sources are not available at this time.

6.1 DATA ATTRIBUTE RANKING SYSTEM (DARS) SCORES

DARS is a system for evaluating the quality of data used in an emission inventory. To develop a DARS score, one must evaluate the reliability of eight components of the emissions estimate. Four of the components are related to the activity level (e.g., the amount of biochemical oxygen demand, or BOD, in wastewater treated anaerobically). The other four components are related to the emission factor (e.g., the amount of methane released per unit of BOD in wastewater treated anaerobically). For both the activity level and the emission factor, the four attributes evaluated are the measurement method, source specificity, spatial congruity, and temporal congruity. Each component is scored on a scale of zero to one, where one represents a high level of reliability. To derive the DARS score for a given estimation method, the activity level score is multiplied by the emission factor score for each of the four attributes, and the resulting products are averaged. The highest possible DARS composite score is one. A complete discussion of DARS may be found in Chapter 4 of Volume VI, *Quality Assurance Procedures*.

The DARS scores provided here are based on the use of the emission factors provided in this chapter, and activity data from the sources referenced in the various steps of the methodology. If a state uses state data sources for activity data, the state may wish to develop a DARS score based on the use of state data.

TABLE 12.6-1

DARS SCORES: CH_4 EMISSIONS FROM MUNICIPAL WASTEWATER AND SLUDGE

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	5	Because the emission factor is not based on measurement, the highest possible score is 5. It is assumed that the Metcalf and Eddy (1972) study used pilot study data.	4	Uncertainty arises if the state uses default values for factors such as the fraction of wastewater treated anaerobically, or the fraction of BOD removed as sludge.	0.20
Source Specificity	6	The emission factor was developed for wastewater treatment, with moderate to high variability.	5	The "activity" measured (population) is somewhat correlated to the emissions process.	0.30
Spatial Congruity	5	The emission factor was developed for the U.S. as a whole, and spatial variability is probably moderate to high, varying as a function of several factors.	5	States use state-level activity data to estimate statewide emissions, but variability exists at the treatment system level.	0.25
Temporal Congruity	5	Temporal variability is expected to be moderate to high.	10	States use annual activity data to estimate annual emissions.	0.50
				Composite Score	**0.31**

TABLE 12.6-2

DARS SCORES: N_2O EMISSIONS FROM MUNICIPAL WASTEWATER AND SLUDGE

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	3	The emission factor is an estimate based on available data.	3	Activity level is based on population, estimated protein consumption, and estimated fraction of nitrogen in protein.	0.09
Source Specificity	8	The emission factor was developed for agricultural use of nitrogen fertilizers.	5	Activity data are somewhat correlated to the emissions process.	0.40
Spatial Congruity	7	The emission factor is based on global, not US, data. Spatial variability is expected to be moderate.	7	States use state-level population data and global estimates for protein consumption and nitrogen fraction in protein, to estimate statewide emissions. Spatial variability is expected to be moderate.	0.49
Temporal Congruity	5	The emission factor is based on an assumption that all N_2O emissions from nitrogen fertilizers, wastewater, or sludge are emitted in the same year the fertilizer is applied or the wastewater or sludge is generated.	6	States use population data from the most recent census, and the most recent available global estimates for protein consumption and nitrogen fraction in protein, to estimate annual emissions. Temporal variability is expected to be moderate.	0.30
				Composite Score	**0.32**

7

REFERENCES

Intergovernmental Panel on Climate Change (IPCC) 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. Bracknell, England: IPCC.

Spector, M. 1997. “Production and Decomposition of Nitrous Oxide During Biological Denitrification,” Unpublished, Lehigh University, Bethlehem, PA.

Thorneloe, S.A., 1992. “Emissions and Mitigation at Landfills and Other Waste Management Facilities,” *Proceedings from EPA Symposium on Greenhouse Gas Emissions and Mitigation Research*.

United Nations Food and Agriculture Association (FAO), 1997. *FAOSTAT Statistical Database*. Internet address: http://apps.fao.org/lim500/nph-wrap.pl?CBD.NonPrimaryLivestockAndProducts&Domain=CBD.

U.S. EPA (U.S. Environmental Protection Agency). 1998. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 1996*. EPA 236-R-98-006. Internet address: http://www.epa.gov/globalwarming/inventory/1998-inv.html.

U.S. EPA (U.S. Environmental Protection Agency). 1999. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 1997.* EPA 236-R-99-003. Internet address: http://www.epa.gov/globalwarming/inventory/1999-inv.html.

U.S. Environmental Protection Agency (U.S. EPA 1999) Clean Water Needs Survey Database. Internet address: http://www.epa.gov/owm/foi.htm.

Viessman, Jr., and M.J. Hammer. 1985. *Water Supply and Pollution Control*. Harper & Row Publishers, New York, NY.